

A comparison of two stream gauging systems for measuring runoff and sediment yield on semi-arid watersheds

V. Polyakov, M. Nearing, A. Hawdon USDA-ARS and CSIRO

Introduction

Our ability to understand erosion processes in semi-arid ecosystems depends on establishing relationships between rainfall, runoff and sediment yield and determining the key factors that influence these relationships. This requires collection of extensive and accurate hydrologic data sets. A supercritical flume with traversing slot sediment sampler used on several sites at Walnut Gulch Experimental Watershed (WGEW) near Tombstone, AZ proved to be a reliable way to measure flow and sediment discharge from small watersheds. However, it requires installation of a costly permanent structure that interferes with erosion process and is only suitable for relatively small flows. CSIRO Land and Water (Australia) developed an alternative in-channel fully automated system for measuring water velocity, depth, turbidity and collecting runoff samples. A 3.7 ha arid watershed at WGEW was instrumented with both systems and hydrologic data was collected and compared during 15 month period (7 runoff events). Total sediment yield for the entire period measured by pump sampler (9.7 t ha⁻¹) was underestimated by 16% comparing to traversing slot sampler (11.5 t ha⁻¹). Pump sampler consistently underestimated the amount of coarse (>0.5 mm) sediment fractions. Median sediment diameter of samples collected by traversing slot and pump sampler were 0.35 and 0.28 mm respectively. Water turbidity was well correlated with concentration of fine (<0.5 mm) sediment ($R^2 = 0.71$) and could be used to supplement sediment data for non-sampled and under sampled runoff events. The study outlines the limitations of the pump sampler based system and makes recommendations for improvement of its performance.

Objectives

- Test a simpler alternative to an existing flume-based watershed gauging system
- Provide a platform to verify sediment data obtained by traversing slot sediment sampler
- Identify limitations and determine ways to improve the performance of the in-stream gauging system

Methods

Watershed 103, Walnut Gulch Experimental Watershed
Rainfall: 292 mm y⁻¹
Area: 3.7 ha
Average slope: 5%
Soil: 39% gravel, 32% sand, 16% silt, and 13% clay
Vegetation: creosote, whitethorn



Figure 1. Watershed 103 at Walnut Gulch Experimental Watershed.

Flume setup

- Smith-type supercritical flow flume rated up to 1.4 m³ s⁻¹.
- Stage recorder (stilling well and float).
- Traversing sediment sampler
 - traversing slot (13 mm wide) travels across the outlet of the flume and diverts portion of the flow into 2-liter bottles placed in a conveyer.
 - triggered when flow depth > 0.06 m
 - sampling intervals: 3 min during the first 15 min of runoff, 5 min between 15 and 30 min of runoff, and 10 min if runoff continues after 30 min.

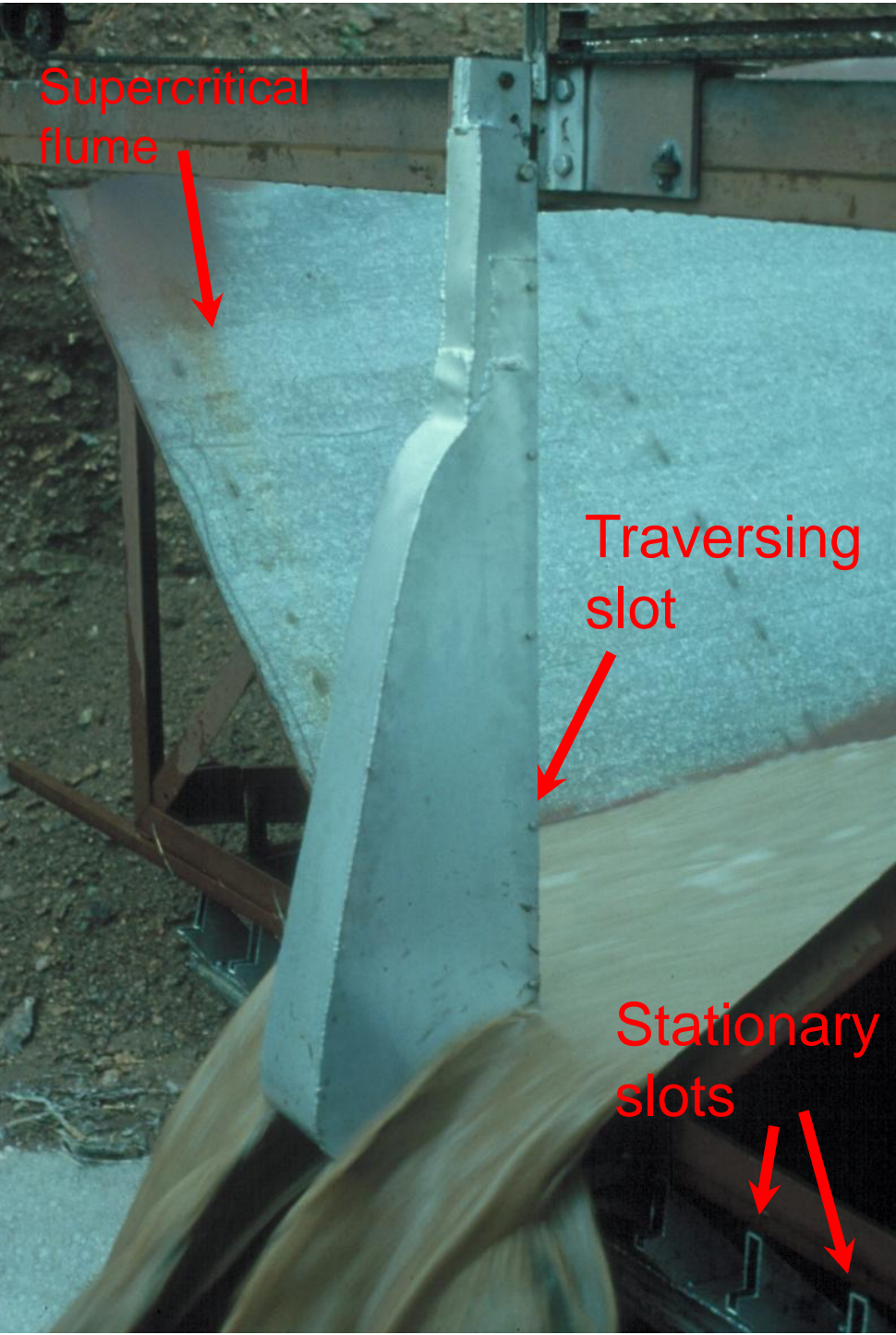


Figure 2. Traversing slot sediment sampler during operation.

In-channel setup

- Water auto sampler (ISCO 3700) uses peristaltic pump to collect up to 24 one-liter samples.
- Collection is triggered by pressure transducer.
- Flow depth is arbitrarily divided on several vertical intervals. Sample is collected if water level changes from the current interval into the adjacent one, or if specified minimal time interval is exceeded.
- Hose is purged prior to taking each sample.
- Flow depth is measured by pressure transducer (Greenspan Analytical PS7000) and is used to detect a flow, trigger autosampler, and estimate discharge.
- Ultrasonic doppler flow velocity meter (Unidata Starflow)
- Turbidity sensor (Analite NEP180, McVan Instruments) with 0-30000BTU range.
- Sensors are controlled by a programmable data logger.

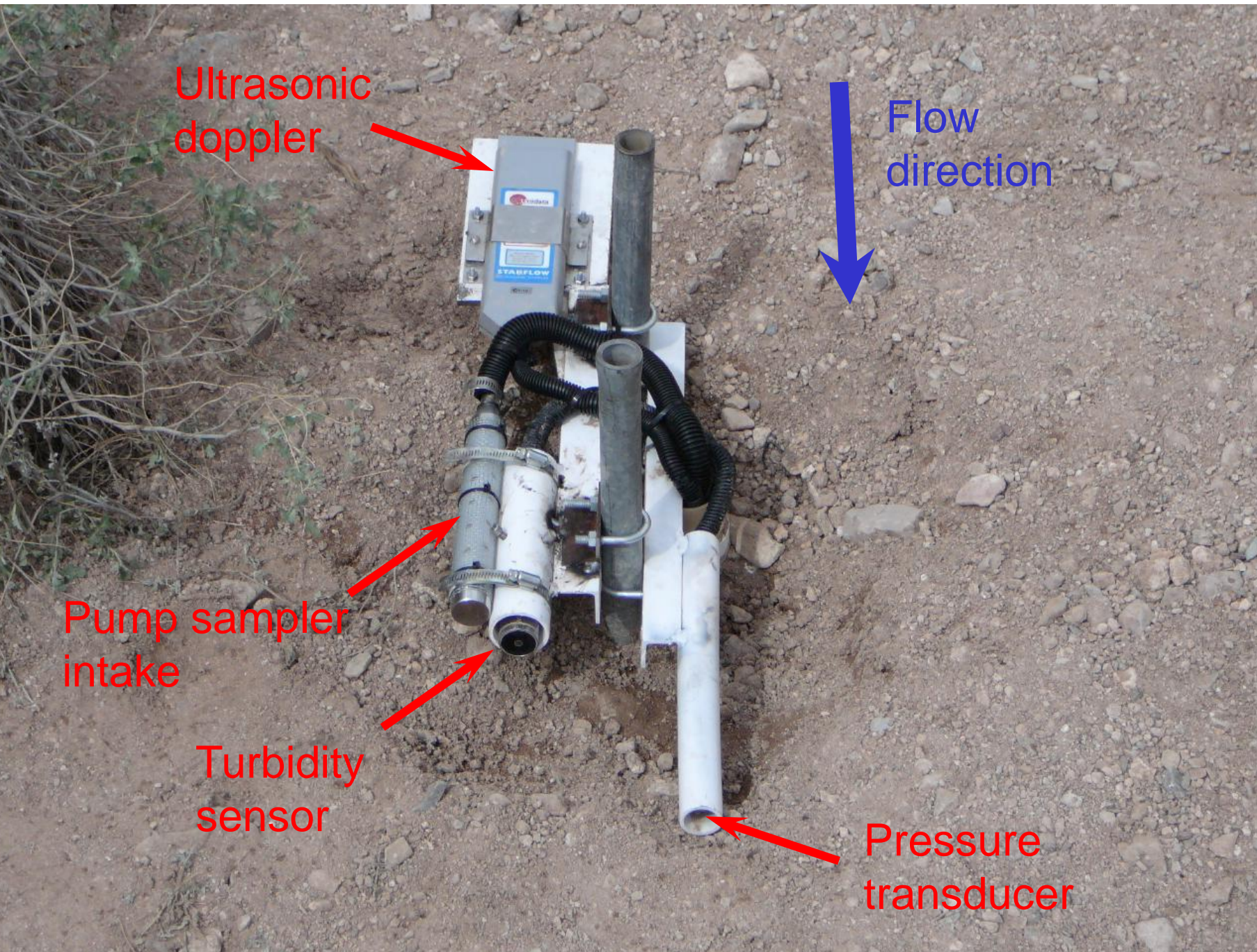


Figure 3. Automated Water Quality Stream Gauging System.

Table 1. Comparison of basic features of two watershed gauging systems.

	Flume	In-channel
Construction	Permanent (fixed erosion base level)	Semi-mobile (minimal flow obstruction)
Max. flow rate, m ³ s ⁻¹	1.4	Not limited
Sample intake	Depth integrated	Point
Max. sediment size, mm	13	6
Capacity, samples	20	24
Sampling interval	Fixed	Dynamic
Other measurements	Stage (flow rate)	Pressure, velocity, turbidity, temperature (channel cross section is needed to estimate flow rate)

Results

More than 90 rainfall events with total precipitation of 420 mm occurred during the observation period starting in July 2009. Among the rainfall events, only eight (160 mm) produced measurable runoff (50 mm or 30% of precipitation) and sediment yield (12.4 t ha⁻¹). The largest storm (7/26/09, 37.8 mm) represented a return frequency of approximately four years. The average annual sediment yield for this watershed (11 year of records) was 5.66 t ha⁻¹ y⁻¹.

Table 2. Rainfall evens and their characteristics during the study period.

Date	Precipitation, mm	-----Runoff ----- Total, mm	Peak, mm/h	----- Sediment ----- t/ha	Pump
8/13/09	11.4	2.5	14.1	0.41	0.24
10/28/09	2.0	1.5	3.2	-	-
7/25/10	22.6	3.5	12.2	0.87	failed
7/26/10	37.8	20.7	67.2	5.99	3.20
7/27/10	21.7	10.6	61.4	2.09	2.46
7/29/10	19.6	3.4	21.5	0.86	0.81
7/30/10	15.7	1.8	10.4	0.47	0.78
8/7/10	10.7	3.3	30.3	0.95	0.54
8/28/10	13.8	3.0	12.2	0.75	1.71
9/22/10	5.3	0.2	0.9	-	-
Total	160	51		11.5*	9.7
Total for the period	242	51		12.4	

* Does not include 7/25/10 event.

Flow depth as measured by pressure transducer was in good agreement with flume stage recorder. Pressure transducer performed reliably regardless of sensors inundation by sediment. Due to frequent velocity meter failures we were unable to estimate discharge and compare it to flume measurements.

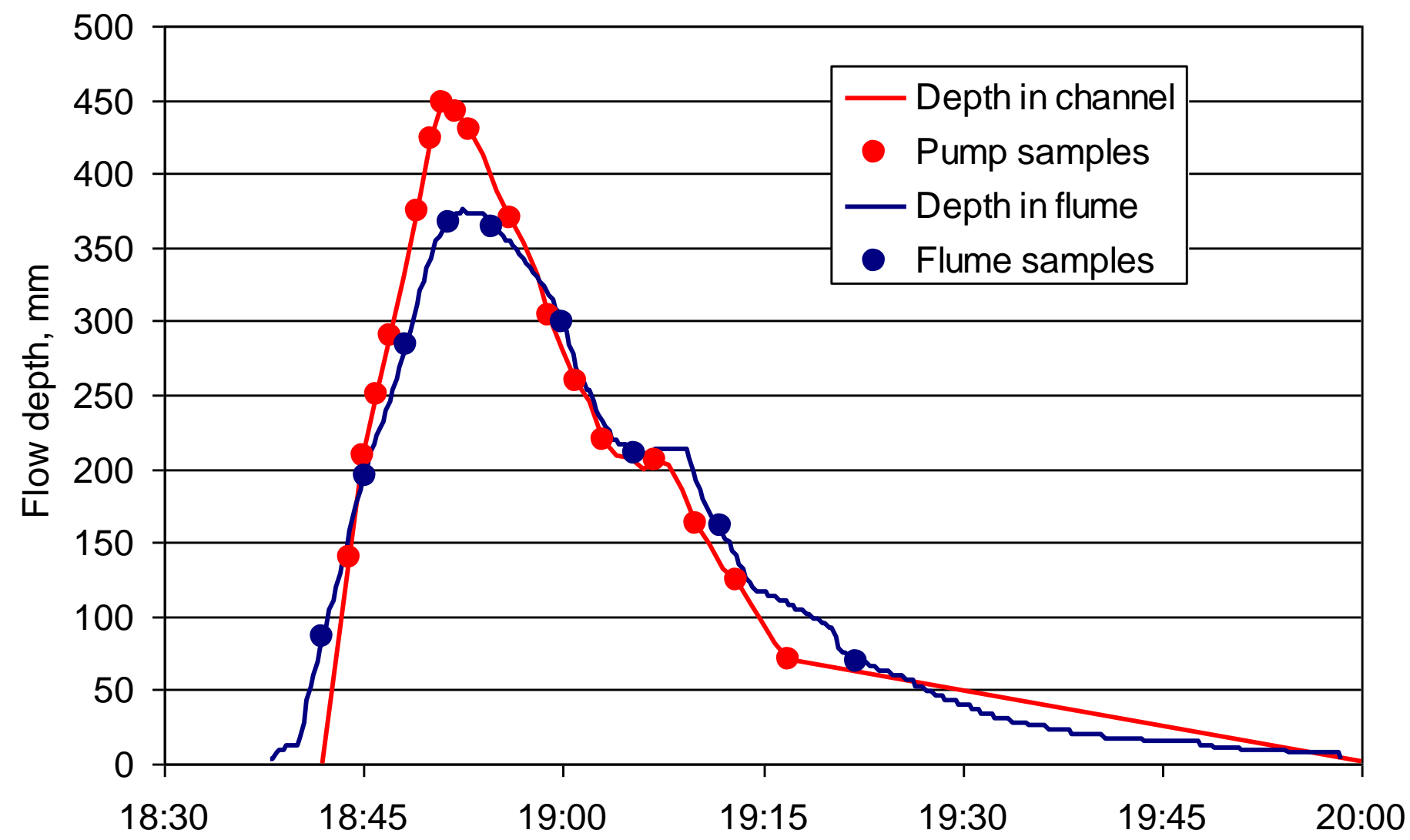


Figure 4. Runoff event on 07/26/2010.

Event sediment yield varied between 6.0 t ha⁻¹ to 0.4 t ha⁻¹ Total sediment yield for the entire study period measured by traversing slot sampler (11.5 t ha⁻¹) was 16% greater than that measured by pump sampler (9.7 t ha⁻¹). However, total suspended sediment load (<0.5 mm) measured by both system was nearly identical with 6.9 and 7.1 t ha⁻¹ for slot and pump sampler respectively. Median sediment diameter of samples collected by traversing slot and pump sampler were 0.35 and 0.28 mm respectively.

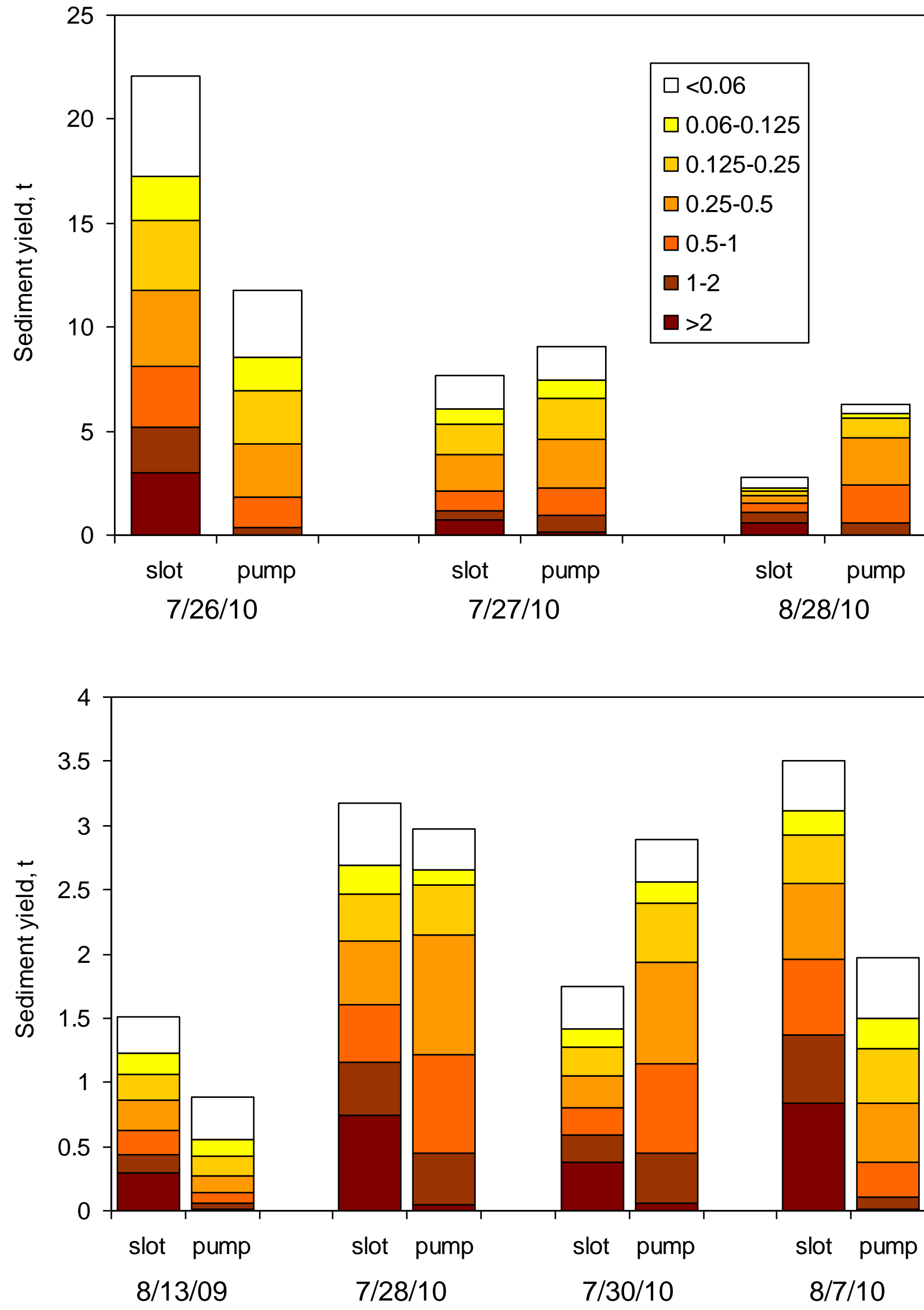


Figure 5. Total sediment yield and particle size distribution as determined from traversing slot (flume) and pump samplers.

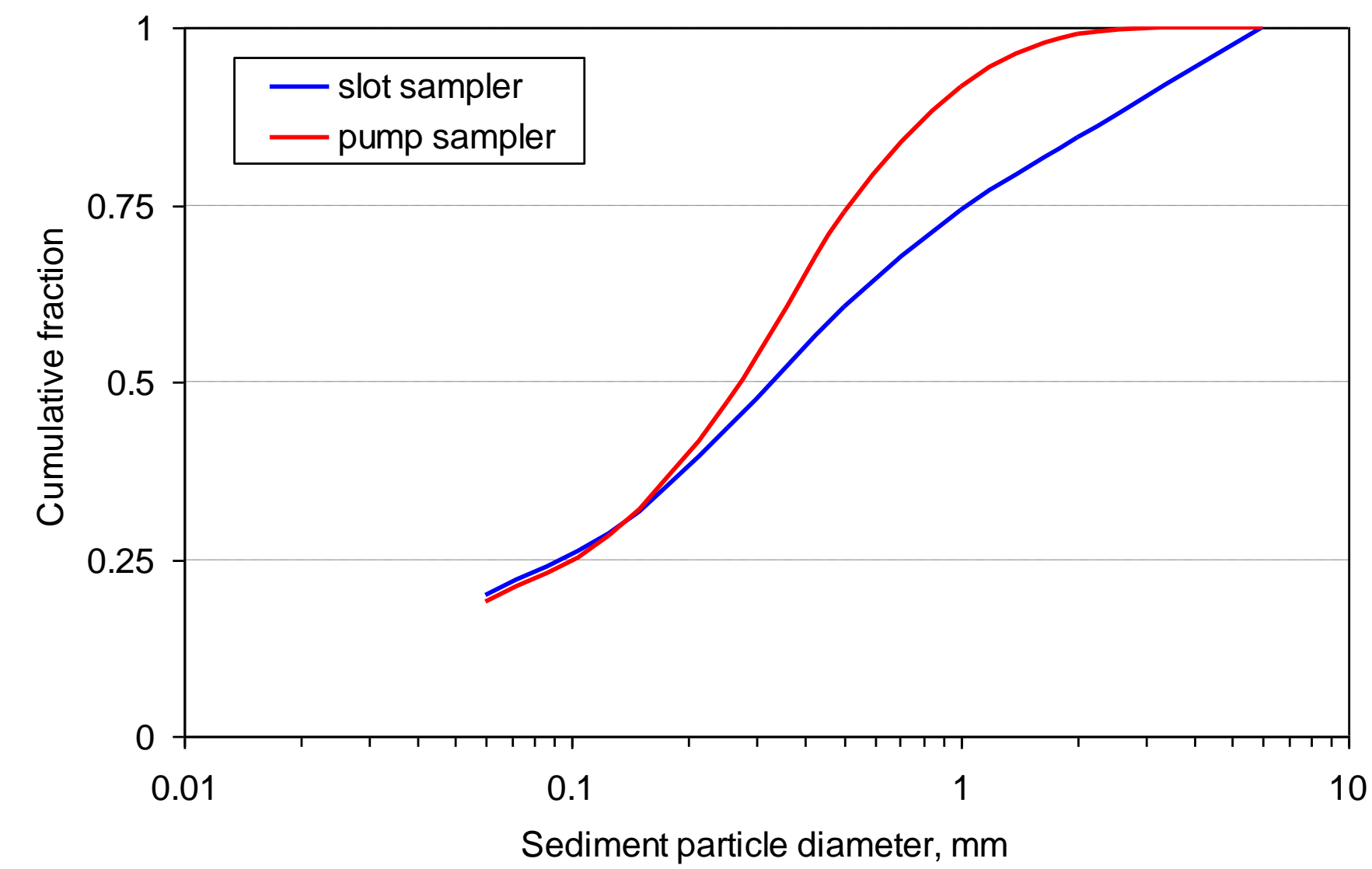


Figure 6. Particle size distribution of sediment collected by slot and pump samplers.

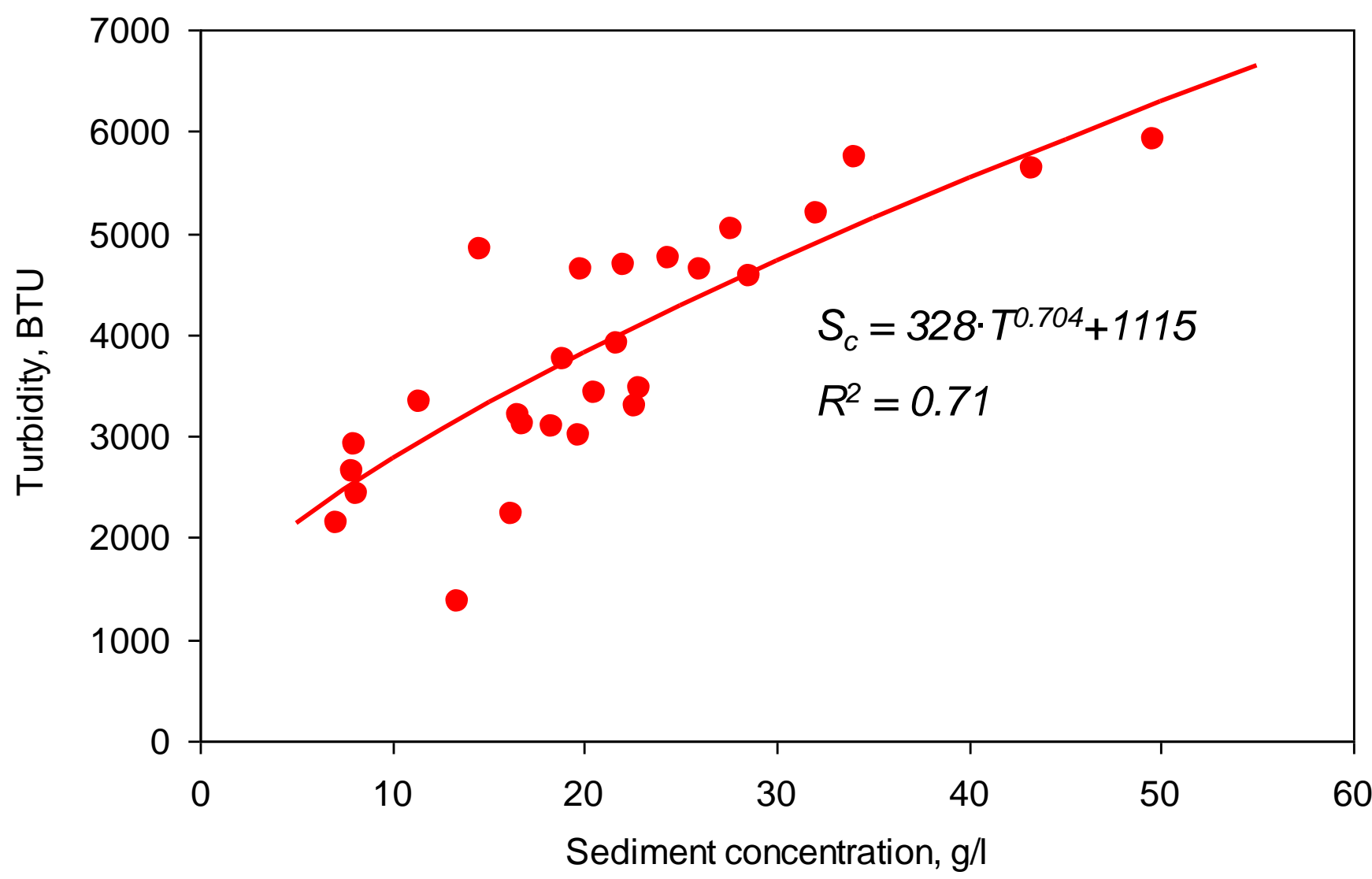


Figure 7. Relationship between runoff turbidity and suspended sediment (<0.5mm) concentration for all events combined.

In order to take measurements in the lower portion of hydrograph the sensors were installed close to the channel bottom. This resulted in reoccurring failures of the doppler velocity meter.



Figure 8. Sensors in a shallow flow, inundated, and with doppler obstructed.

Conclusions

- In-channel measuring system causes minimal flow obstruction and interference with erosion process
- Estimates of total and suspended sediment loads are adequate
- Coarse sediment fraction (>0.5 mm) is underestimated
- Better suited for larger flows, low position of the sensors results in measurement failures
- Variable sample timing adapts to the changes in hydrograph resulting in more accurate sampling
- Turbidity data can be used to supplement suspended sediment load measurements
- Installation and relocation is relatively easy due small size and standard components
- Sampling (particle distribution) can be improved by using floating type perforated tube intake instead of point intake.